IB · DP · Physics

3 hours   15 questions

Structured Questions

6.1 Circular Motion

6.1.1 Circular Motion / 6.1.2 Centripetal Force / 6.1.3 Centripetal Acceleration / 6.1.4 Applications of Circular Motion

Easy (5 questions)	/65
Medium (5 questions)	/49
Hard (5 questions)	/42
Total Marks	**/156**

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Easy Questions

1 (a) A bung is attached to a rope and a person swings the bung around their head. The bung moves in a horizontal circular path.

Circle four options from the list below, which are properties of all objects moving in a circle.

Period   Heat energy   Electricity   Frequency   Decay constant

Angular displacement   Capacitance   Angular speed   Strangeness

(4 marks)

(b) The length of the rope is *r*, and the bung is moving with velocity *v*. It is acted upon by force *F*.

Sketch the shape of the bung's path, labelling *r*, *v* and *F*.

(3 marks)

(c) The bung travels though an angular displacement of $\frac{\pi}{8}$ rad.

Convert the angular displacement into degrees.

(3 marks)

(d) It takes 0.5 s for the bung to complete one revolution. The radius of its circular path is 0.75 m.

(i) Calculate the angular speed of the bung.

[4]

(ii) Calculate the linear speed of the bung.

[2]

(6 marks)

2 (a) A car is moving with uniform circular motion and experiences a centripetal force.

(i) Define centripetal force.

[3]

(ii) State the type of force which is responsible for the centripetal force on the car.

[1]

(4 marks)

(b) The car has mass 500 kg and is travelling around a roundabout with a linear speed of 9 m s^{-1}. The radius of the roundabout is 12 m.

Determine the centripetal force acting on the car.

(2 marks)

(c) The car proceeds to another roundabout which has radius 20 m. The angular speed of the car at this roundabout is 0.2 rad s^{-1}.

Calculate the centripetal acceleration of the car around this roundabout.

(3 marks)

(d) At this second roundabout, the car is travelling at the maximum speed possible before it would skid. The coefficient of static friction determines the maximum speed possible and is given by $\mu_s = \frac{\omega^2 r}{g}$, where ω is the angular speed, r is the radius of the roundabout, and g is the acceleration due to gravity.

Determine the co-efficient of static friction between the tyres and the road.

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(2 marks)

3 (a) A planet orbits a star in 260 Earth days, which is 22 464 000 s.

(i) State the angular displacement of the planet in 260 days, giving an appropriate unit with your answer.

[2]

(i) Calculate the angular speed of the planet.

[4]

(6 marks)

(b) The linear speed of the planet is 35 000 m s^{-1}.

Calculate the radius of the planet's orbit.

(2 marks)

(c) The planet has a mass of 2.7×10^{24} kg and stays in orbit due to a centripetal force.

Calculate the centripetal force required to keep the planet in orbit.

(2 marks)

(d) The planet experiences a centripetal acceleration.

(i) Define uniform centripetal acceleration

[3]

(ii) Determine the centripetal acceleration experienced by the planet.

[2]

(5 marks)

4 (a) A fairground ride is moving with uniform circular motion.

(i) Define angular displacement.

[2]

(ii) Define angular speed.

[1]

(3 marks)

(b) A child on the ride has an angular displacement of $\frac{\pi}{2}$ rad and angular speed of 0.3 rad s^{-1}.

Calculate the time required for the child to have this angular displacement.

(4 marks)

(c) The radius of the ride is 8 m and the child's mass is 35 kg.

Determine the centripetal force on the child.

(2 marks)

(d) (i) Calculate the child's linear speed.

[2]

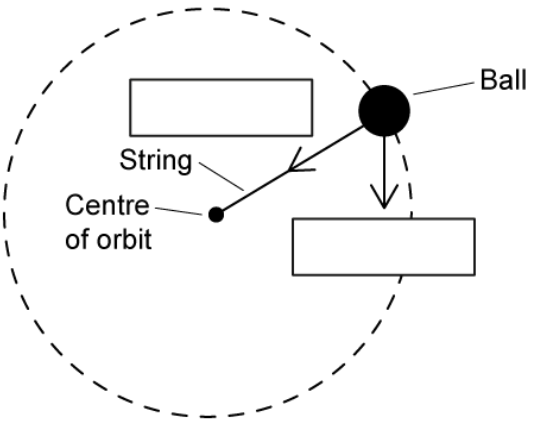
(ii) Calculate the child's centripetal acceleration.

[2]

(4 marks)

5 (a) The diagram shows the bath of a ball with two forces acting on it. The ball is attached to a string and is swung in a circle in a vertical plane. Air resistance is negligible.

(i) Label the forces marked on the diagram below:



[2]

(ii) State which of these forces provides the centripetal force on the ball.

[1]

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(3 marks)

(b) The centripetal force on the ball is not constant as the ball travels along its circular path.

Circle the correct words in the sentences below:

The **maximum / minimum** magnitude of centripetal force is found at the bottom of the circular path.

The **maximum / minimum** magnitude of centripetal force is found at the top of the circlular path.

....

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(2 marks)

(c) The radius of the circle is 0.8 m, the mass of the ball is 0.5 kg and the linear velocity is 2.4 m s^{-1}.

Calculate the centripetal force at the bottom of its circular path.

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(3 marks)

(d) The speed and acceleration of the ball varies as it moves around its circular path.

Circle the correct words in the sentences below:

The speed of the ball at the bottom of the circular path will be **faster / slower** than at the top.

The acceleration at the bottom of the circular path will be at a **minimum / maximum** compared to the top.

....

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(2 marks)

Medium Questions

1 (a) A lead ball of mass 0.55 kg is swung round on the end of a string so that the ball moves in a horizontal circle of radius 1.5 m. The ball travels at a constant speed of 6.2 m s^{-1}.

Calculate the time taken for the string to turn through an angle of 170º.

(3 marks)

(b) Calculate the tension in the string.

(2 marks)

(c) The string will break when the tension exceeds a maximum tension. The ball makes three revolutions per second at the maximum tension of the string.

Calculate the tension above which the string will break.

(2 marks)

(d) Describe, using just one of Newton's Laws, why the ball is accelerating even when its angular speed is constant.

You may wish to draw a diagram to clarify your answer.

(3 marks)

2 (a) Explain why a particle moving in a circle with uniform speed is accelerating.

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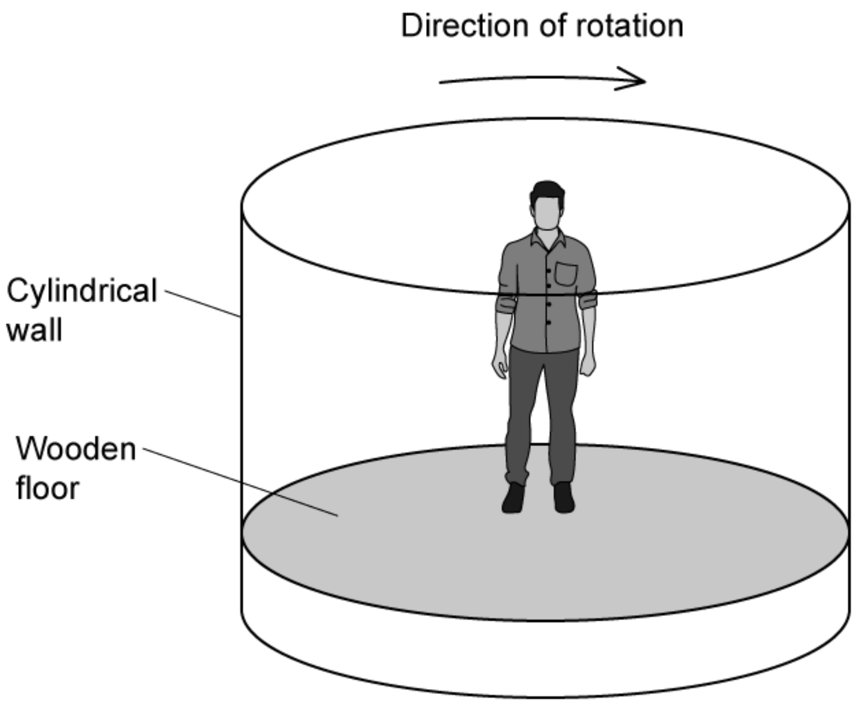
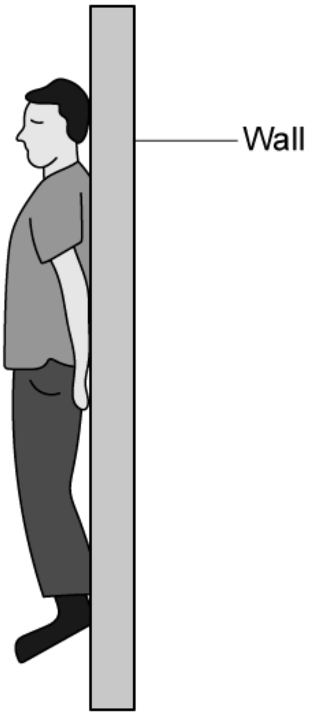
(2 marks)

(b) The diagram shows a fairground ride called a Rotor. Riders stand on a wooden floor and lean against the cylindrical wall.



The fairground ride is then rotated. When the ride is rotating sufficiently quickly the wooden floor is lowered. The riders remain pinned to the wall by the effects of the motion. When the speed of rotation is reduced, the riders slide down the wall and land on the floor.

At the instant shown in below the ride is rotating quickly enough to hold a rider at a constant height when the floor has been lowered.



Explain why the riders slide down the wall as the ride slows down.

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(2 marks)

(c) A rotor accelerates uniformly from rest to maximum angular velocity of 3.6 rads s^{-1}. At the maximum speed the centripetal acceleration is 35 m s^{-2}.

Calculate the diameter of the rotor.

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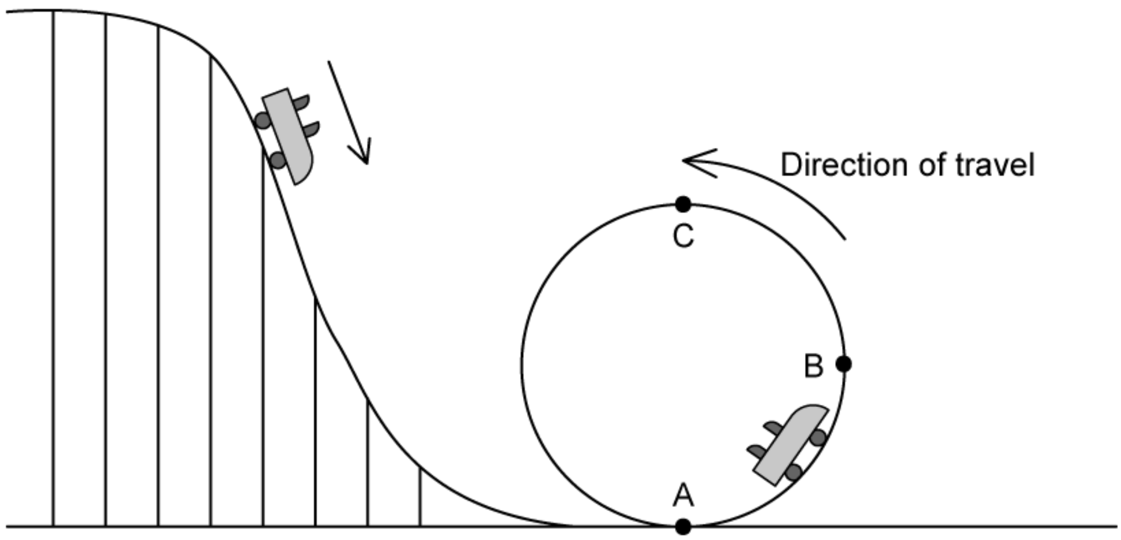
(2 marks)

(d) The diagram shows the final section of a roller coaster which ends in a vertical loop. Cars on the roller coaster descend to the start of the loop and then travel around it.

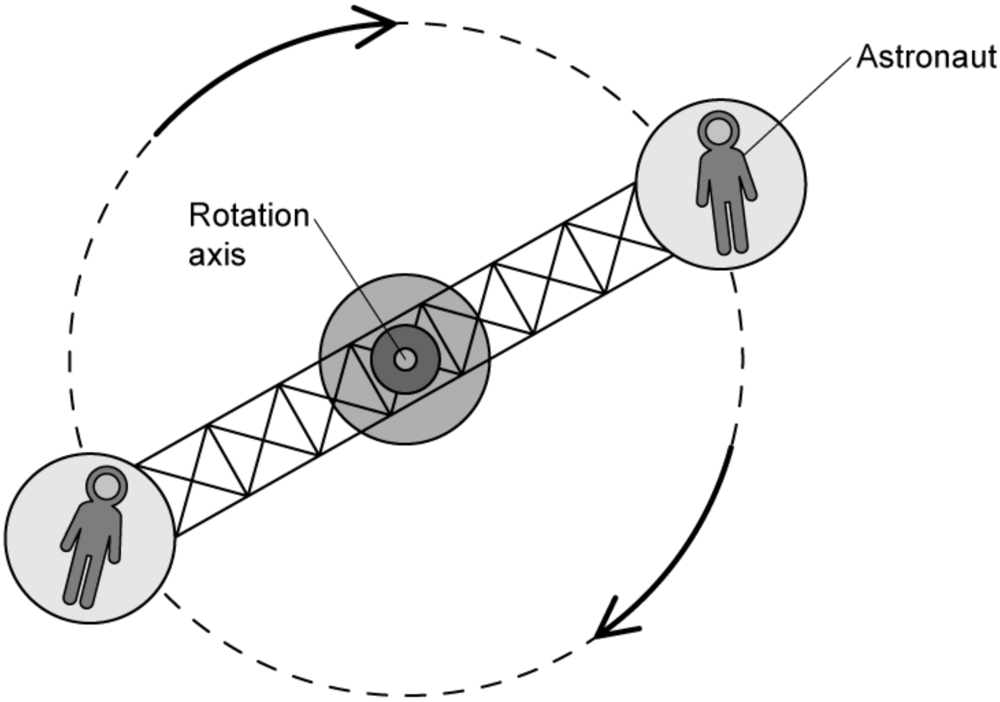


As the passengers move around the circle from **A** to **B** to **C**, the reaction force between exerted by their seat varies.

State the position at which this force will be a maximum and the position at which it will be a minimum. Explain your answers.

(4 marks)

3 (a) A centrifuge is often used in astronaut training. This is to simulate Earth's gravity on board the space station. The astronauts sit in a cockpit at the end of each arm, each rotating about an axis at the centre.



At its top speed, the centrifuge makes 1 full rotation every 2.30 s.

Calculate the frequency of the centrifuge. State an appropriate unit and express your answer to an appropriate number of significant figures.

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(3 marks)

(b) Calculate the angular speed of the centrifuge in rad s^{-1}.

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(2 marks)

(c) Each astronaut is placed 6.30 m from the rotation axis.

Calculate the magnitude of the centripetal acceleration on each astronaut.

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(2 marks)

(d) Sketch the direction of the acceleration on each astronaut.

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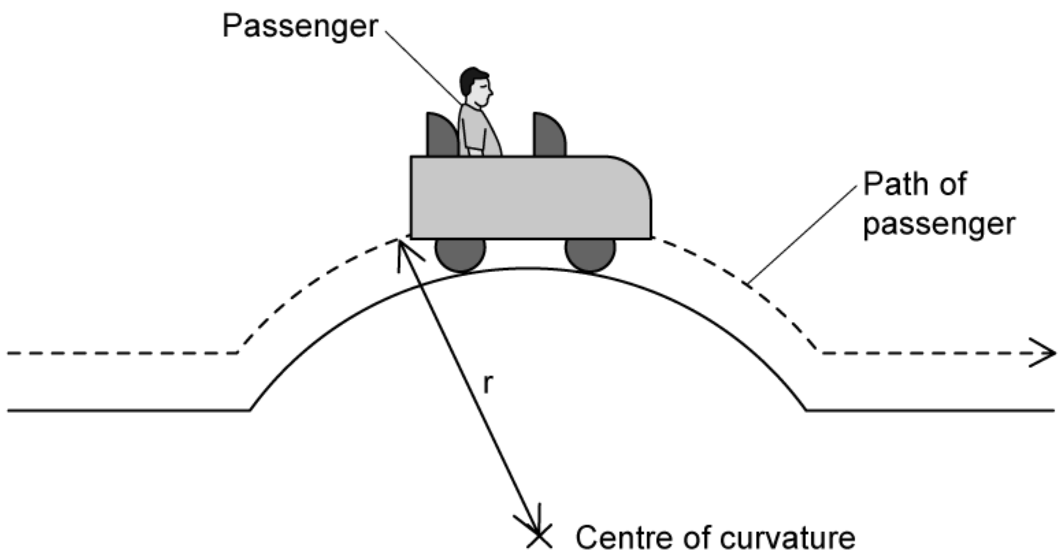
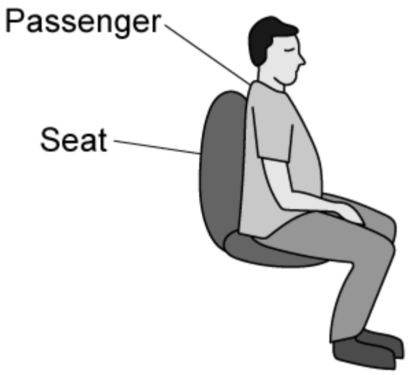
(1 mark)

4 (a) A section of a roller coaster carries a passenger over a curve in the track. The radius of curvature of the path of the passenger is *r* and the roller coaster is travelling at constant speed *v*. The mass of the passenger is *m*.



(i) Draw the forces that act on the passenger as they pass over the highest point on the curved track.

(ii) Write down an equation that relates the contact force *R* between the passenger and the seat to *m*, *v*, *r* and the gravitational field strength, *g*.



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(2 marks)

(b) At a particular point on the track, the car moves with a linear velocity of 22 m s^{-1}. The reaction force between the car and the track at this point is 210 N and the passenger has a mass of 65 kg.

Calculate the distance from the passenger to the centre of curvature of the curved track.

(3 marks)

(c) State and explain what would happen to the magnitude of *R* if the rollercoaster passed over the curved track at a higher speed.

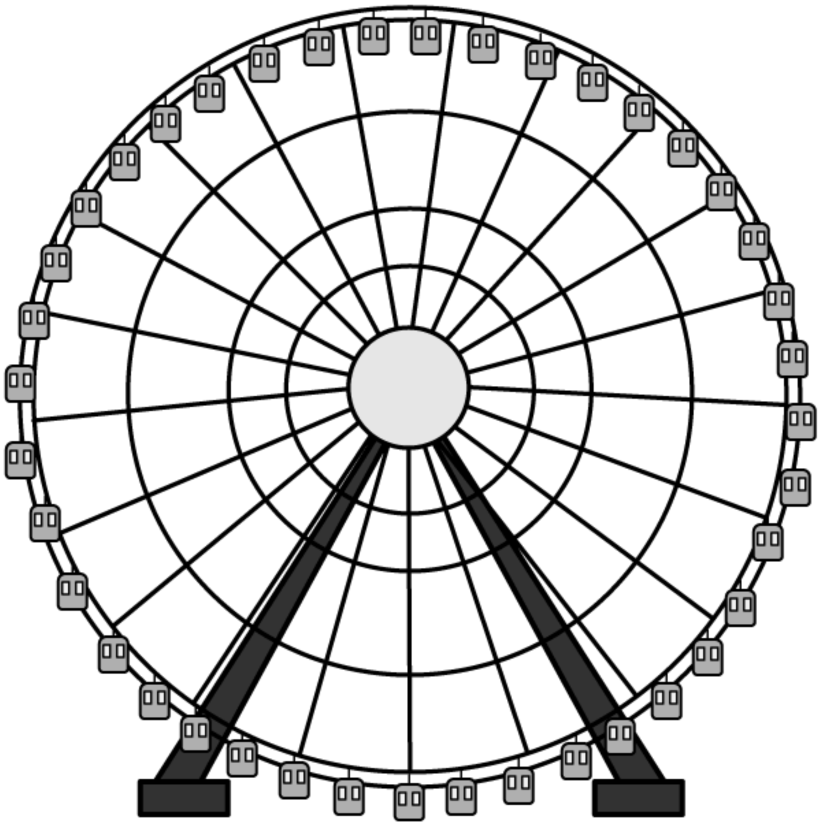
(2 marks)

(d) When the rollercoaster passes over a curved section of a track above a certain speed, the passenger is momentarily lifted off their seat and experiences weightlessness.

Calculate the speed at which the rollercoaster must be travelling for the passenger to experience weightlessness.

(3 marks)

5 (a) The London Eye shown in the diagram has a radius of approximately 68 m and the passengers in the capsules travel at an angular speed of 3.5×10^{-3} rad s^{-1}.



Calculate the speed of each passenger in the capsules.

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(2 marks)

(b) Assume the London Eye is rotating clockwise.

Sketch the following on any capsule:

(i) The direction of the centripetal force *F*

(ii) The direction of the linear speed *v*.

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(2 marks)

(c) Each capsule weighs about 98.1 kN.

Calculate the centripetal force on an empty capsule.

(3 marks)

(d) Dan has travelled to London to watch an exciting Physics show. Being an eager tourist, he arrives early and plans to ride the London Eye. When he gets to the front of the queue however, he realises he only had 40 minutes before he needs to leave for the show.

State, with a calculation, whether Dan is still able to ride the London Eye and leave to see the show on time.

(4 marks)

Hard Questions

1 (a) A proton of mass *m* moves with uniform circular motion. Its kinetic energy is *K* and its orbital period is *T* .

Show that the orbital radius *r* is given by:

$$r = \sqrt{\frac{KT^2}{2\pi^2 m}}$$

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(2 marks)

(b) The proton moves in a clockwise circle of circumference 1.25 mm. The net force on the proton is 65 fN.

Determine the linear speed of the proton.

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(3 marks)

(c) Calculate the proton's orbital frequency.

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(3 marks)

(d) (i) State the mechanism by which protons are made to travel in circular paths.

[1]

(ii) Comment on the work done on the proton by this mechanism.

[2]

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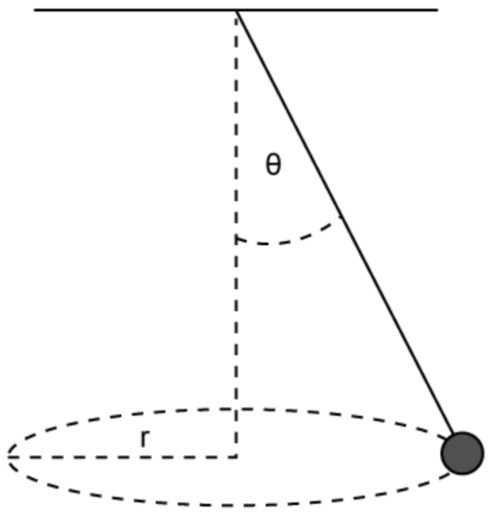
(3 marks)

2 (a) A small ball is attached to a string and moves in a horizontal circular path. It completes one revolution every 2.5 s, with the string at an angle θ to the vertical.



Calculate the orbital radius *r* if θ = 12°.

You may wish to use the following data:

$$\tan\theta = \frac{\sin\theta}{\cos\theta}$$

....

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(3 marks)

(b) Show that the length of the string *l* is given by:

$$l = \frac{g}{\omega^2 \cos\theta}$$

You may wish to use the following data:

$$\tan\theta = \frac{\sin\theta}{\cos\theta}$$

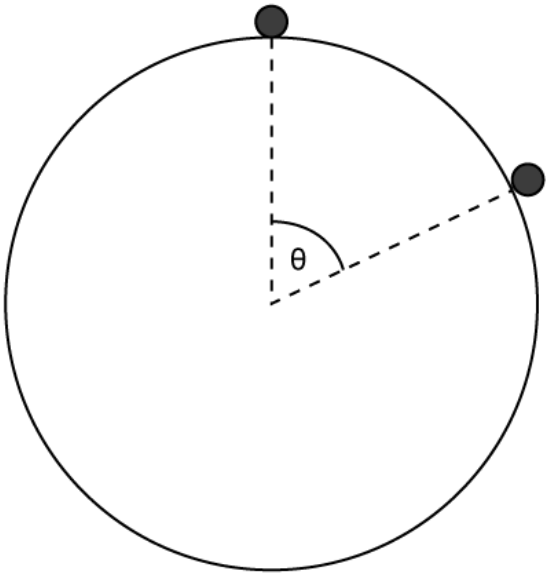
(2 marks)

(c) The equation in part (b) seems to suggest that the length of the string *l* is dependent on the angle it makes to the vertical, θ.

Comment on the relationship between the length of the string *l* and the angle it makes to the vertical, θ.

(2 marks)

3 (a) A marble rolls from the top of a bowling ball of radius *R*.



Show that when the marble has moved so that the line joining it to the centre of the sphere subtends an angle of θ to the vertical, its speed v is given by:

$$v = \sqrt{2gR(1 - \cos\theta)}$$

(3 marks)

(b) Deduce that, at the instant shown in the image in part (a), the normal reaction force N on the marble from the bowling ball is given by:

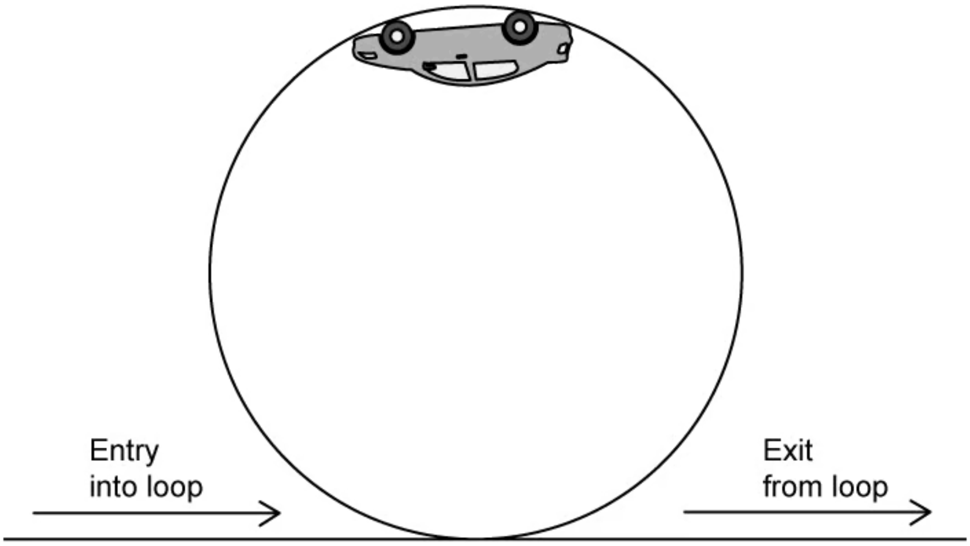
$$N = mg(3\cos\theta - 2)$$

(4 marks)

(c) Hence, determine the angle θ at which the marble loses contact with the bowling ball.

(2 marks)

4 (a) The 'loop-the-loop' is a popular ride at amusement parks, involving passengers in cars travelling in a vertical circle.



The loop has a radius of 8.0 m and a passenger of mass 70 kg travels at 10 m s^{-1} when at the highest point of the loop.

Calculate, at the highest point:

(i) the centripetal acceleration of the passenger,

[1]

(ii) the force that the seat exerts on the passenger.

[2]

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....

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(3 marks)

(b) Stating any assumptions required, calculate the speed of the passenger at the point marked 'exit from loop' in part (a).

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(3 marks)

(c) Operators must ensure that the speed of the vehicle carrying passengers into the loop-the-loop is above a certain value.

Suggest a reason for this, and determine the minimum required speed.

(2 marks)

5 (a) A popular trick to impress young observers is to swing a bucket of water in a vertical circle. If the bucket is swung fast enough, no water spills out.

Estimate the minimum linear speed *v* required to swing a bucket in a vertical circle, such that no water spills.

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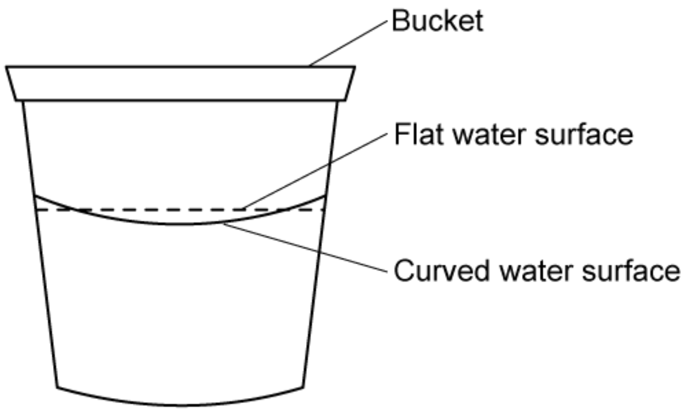
(3 marks)

(b) When the bucket of water is stirred with a spoon in uniform circular motion near the rim, the level of water in the bucket is observed to change from a flat horizontal dashed line to a curved solid line, as shown.



By considering the circular motion of a fluid particle in the water, explain this observation using relevant physical principles.

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(4 marks)